Fizeau Astrometric Mapping Explorer

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Abstract. The Fizeau Astrometric Mapping Explorer (FAME) is a proposed mid-sized satellite that would measure positions, proper motions and parallaxes of all stars down to 15^{th} magnitude from an elliptical high-Earth orbit. The estimated positional accuracy will be better than 50 μas for stars of 9^{th} magnitude and brighter. Colors will also be determined for all stars down to 10^{th} magnitude. The payload has been designed to fit within the envelope of a Delta-Lite launch vehicle. The mission would have a lifetime of 2.5 years, and can be launched by the year 2000 with a total cost of $70M. FAME is a multi-institutional collaboration between NRL, JPL and USNO. The instrumentation and spacecraft bus are under development at JPL and NRL, respectively. Science operations and data analysis are to be carried out at USNO. The principle investigator is Dr. K. Johnston, Scientific Director of the U.S. Naval Observatory.

1. Principle of Operation

FAME works in much the same way as the very successful HIPPARCOS mission. Two fields of view separated by a basic angle are imaged onto a common focal plane as the satellite slowly scans a great circle on the sky. The angular separations between stars within the same instantaneous field of view are directly measured. Observations of the same stars at the beginning and end of each great-circle scan, and the additional constraints afforded when stars traverse the second field of view, allow one to solve for the variations in scale which occur as a result of variations in the rotation rate of the spacecraft. In this way, the position of a star can be related to the positions of other stars around the great-circle scan with uniform precision.

The great circle reduction is followed by the linking together of individual scans using a type of block adjustment. Finally, the astrometric parameters – position, proper motion, and parallax – are determined. Colors are obtained from a dispersed image of the stars in one of the fields of view.

2. Technical Challenges

2.1. CCD Mosaic

Starlight is imaged onto a mosaic of twelve 4096 by 1024 two-side buttable CCD's operated in scanning mode. This will be the largest CCD mosaic ever flown. The astrometric goals place stringent requirements on the the alignments, clock rates, and read noise.

2.2. Attitude Control

The use of scanning CCD's places stringent requirements on the attitude control for FAME. Star images must be scanned parallel to the CCD pixel rows, and the rotation rate of the satellite must not fluctuate faster than the CCD clock rate can be updated. The attitude and rotation rate are adjusted using cold-gas thrusters. The number of thruster firings per great-circle scan must be minimized, however, in order to preserve the precise timing which relates star positions to one another along the scan. These conflicting demands can be met if the mass distribution of the spacecraft is nearly spherical, with the center of mass precisely aligned along the Sun vector with the center of pressure.

2.3. Laser Metrology System

Light from each field of view reflects from a separate entrance mirror before entering a common optical train. The angle between these two mirrors defines the basic angle, and will be closely monitored using an innovative laser metrology system. Pulses of laser light emanate from the focal plane, traveling through the optical train to the entrance mirrors. One percent of this light is redirected back through the optics by diffraction gratings on each of the entrance mirrors, forming interference fringes on the CCD's. These fringes are analyzed to detect changes in the basic angle. This new technology will be needed for future space interferometric missions.

3. Science from FAME

3.1. Distance Scale

FAME will be able to directly measure distances to approximately 30 Cepheid variable stars and 20 RR Lyrae variable stars, providing a refinement of the period-luminosity-color relation. Proper motion and parallax measurements of stars in the solar neighborhood will lead to more accurate determinations of the Oort A and B constants, providing refinements of both the galactic rotation curve and its derivative and the distance to the center of the Galaxy, upon which the extragalactic distance scale rests.

3.2. Galactic Structure

Several topics of Galactic structure will be addressed by FAME. Distances and proper motions of all spectral types within 2-3 kpc of the Sun will allow kinematic population studies that will assess the local escape speed, mass density, disk dark matter fraction, and the local rotation curve.

3.3. Star Clusters

FAME will be able to measure parallactic distances and proper motions of the 5 nearest globular clusters (1.9 to 3.4 kpc) at the 10-20 percent level. Old open clusters are important for Galactic disk evolution studies; 19 of these lie within 1.7 kpc and can be measured at the 5% level. Young clusters serve as tracers of spiral arms, Galactic rotation, and star formation; useful science can be done at the 50 μas/yr level.

3.4. Stellar Masses

Less than 5% of visual binaries (most of which are less than 20 pc distant) have good mass determinations. FAME, with its 2-3 orders of magnitude parallax measurement improvement, would greatly increase the number of reliable mass determinations. Accurate masses of massive stars would constrain high-mass stellar evolution models.

3.5. Stellar Luminosities

FAME would provide accurate distances to stars of all spectral types, hence improving the mass-luminosity-metallicity-age relationship. Additionally, we could finally obtain definitive absolute magnitude calibrations of early spectral type stars.

3.6. Exotic Objects

Table 1 shows the black hole candidate within reach of FAME. The last column shows the distance error (as a percentage) that would result from FAME measurements. Determination of dynamical masses for these objects could provide conclusive proof for the existence of black holes in these systems.

3.7. White Dwarf Stars

The white dwarf mass distribution has important implications for the progenitor population and Galactic evolution. Currently, distances to the 162 known WDs within 25 pc are poorly known, leading to a poorly calibrated mass-radius relation. FAME would drastically reduce the distance uncertainties to nearly all WDs within 25 pc and significantly improve the WD mass-radius relation.

Table 1. Black hole candidates within reach of FAME

	mv	D(kpc)	M	σ_D(%)
V616 Mon	11.3-20	1	>3-9	5
Nova Mus 1991	13.4-20	1.4	?	20
Cyg X-1	9	2.5	9	6
V404 Cyg	11.5-18	1-3	8-15?	5-15

3.8. Global Reference Frame

The definition of a very accurate global reference frame (GRF) is of considerable astrophysical importance. Currently, position errors in the FK5 catalog are ≈ 10 mas at epoch 1940. Systematic errors are at the 0.1-0.2 arc second level. The current radio/optical frame disparity is roughly 10 mas. FAME would be capable of defining a bias-free GRF at the 50μas level, tied to the radio frame.

3.9. Extra-solar Planetary Systems

Future large space astrometric instruments capable of studying and characterizing exoplanets will likely be pointed missions. A precursor survey instrument like FAME would search for exoplanet candidates among a large sample of stars, serving as a valuable filter for the large missions. Evidence from ground observations already exists for several exoplanets, ranging in mass from 0.5 to 6.6 M_J. The astrometric signature of the Sun due to Jupiter, seen from a distance of 100 pc, is nearly 100 μas (peak to peak). With the nominal 2.5 yr mission, FAME could detect astrometric signatures of large, short-period exoplanets around nearby stars up to several hundred parsecs distant.

3.10. FAME Science Team

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